ACUTE TOXICITY SUMMARY

STYRENE

(vinyl benzene; phenylethylene; cinnamene; styrol; vinylbenzol)

CAS Registry Number: 100-42-5

I. Acute Toxicity Summary (for a 1-hour exposure)

Inhalation reference exposure level	**21,000 μg/m³**
Critical effect(s)	eye and upper respiratory irritation
Hazard Index target(s)	Eyes; Respiratory System; Reproductive/developmental

II. Physical and Chemical Properties (Vainio and Hietanen, 1987 except as noted)

Description	colorless liquid
Molecular formula	C_8H_8
Molecular weight	104.14
Density	0.902 g/cm^3 @ 20°C
Boiling point	145.2°C
Melting point	-30.6°C
Vapor pressure	6.45 mm Hg @ 25°C
Flashpoint	31°C (closed cup) (ATSDR, 1992)
Explosive limits	upper = 6.1% by volume in air lower = 1.1% by volume in air (ATSDR, 1992)
Solubility	soluble in ethanol, ether, acetone, benzene, and petroleum ether; sparingly soluble in water
Odor threshold	1.36 mg/m³ (0.32 ppm) (Amoore and Hautala, 1983)
Odor Description	sweet, sharp odor (Amoore and Hautala, 1983)
Metabolites	styrene 7,8-oxide, styrene glycol, mandelic acids, phenylglyoxylic acids (Leibman and Ortiz, 1970; Sedivec *et al*., 1984)
Conversion factor	1 ppm = 4.2 mg/m³

III. Major Uses or Sources

Styrene is produced by the dehydrogenation of ethylbenzene in the presence of polymerization inhibitors (Vainio and Hietanen, 1987). It is used in the plastics industry as a solvent for synthetic rubber and resins, as a starting material in the manufacture of emulsifying agents, in the manufacture of synthetic rubber and polystyrene, and in the production of propylene oxide (Vainio and Hietanen, 1987).

IV. Acute Toxicity to Humans

Styrene may irritate the eyes and mucous membranes and may be toxic to the central nervous system (IARC, 1979). Immediate eye and throat irritation, increased nasal mucus secretion, listlessness, impairment of balance, and drowsiness followed by unsteadiness, muscle weakness, and depression were reported in a study of 2 human volunteers exposed to 800 ppm (3,360 mg/m³) styrene for 4 hours (Carpenter *et al*., 1944). Other symptoms include a feeling of being "lightheaded" or "drunk" (Lorimer *et al*., 1976).

In an exposure chamber study, volunteer subjects complained of an objectionably strong odor when exposed to 200-400 ppm (840-1,680 mg/m³) styrene; exposure to 60 ppm (252 mg/m³) resulted in detectable odor but no irritation (Wolf *et al*., 1956). The duration of exposure and number of subjects were not specified. Investigators at a fiberglass plant could not withstand more than 1-2 minute exposure to concentrations of 500-800 ppm styrene (Götell *et al*., 1972). However, workers exposed to this concentration of styrene for hours complained of only mild to moderate complaints of irritation, suggesting that tolerance may have developed.

Stewart *et al*. (1968) found eye and throat irritation in 3 out of 6 volunteers exposed to 99 ppm (416 mg/m³) styrene for 20 minutes. No symptoms were reported in 3 subjects after exposure to 51 ppm for 1 hour. Exposure of these subjects to 376 ppm (1,579 mg/m³) styrene for 25 minutes resulted in nausea, significant discomfort, and an abnormal Romberg test, indicative of cerebellar dysfunction. Significant decrements were noted in 3/5 subjects in other tests of coordination and manual dexterity at 50 minutes. Exposure to 216 ppm or less for up to 1-hour did not cause measurable impairment of coordination and balance.

The neurotoxic effects mediated by styrene consist of slowing in sensory, but not motor, nerve conduction velocity and CNS depression (Cherry and Gautrin, 1990). Reaction time was significantly impaired in 12 males exposed to 350 ppm (1,470 mg/m³) styrene for 30 minutes, whereas no significant impairment was observed at 250 ppm (1,050 mg/m³) or lower (Gamberale and Hultengren, 1974). In this study, no effects on perceptual speed or manual dexterity were detected. In another study of 12 workers exposed during the workday to 110 mg/m³ (26 ppm), Edling and Ekberg (1985) measured reaction time before and after work and found no significant differences. Other non-CNS symptoms were reported in a neuropsychiatric questionnaire completed by the subjects.

Abnormal electroencephalograms were correlated with urinary levels of the styrene metabolite, mandelic acid, of 700 mg/l or higher in workers exposed to styrene (Harkonen *et al*., 1978).

Consumption of ethanol has been shown to decrease formation of the metabolites mandelic and phenylglyoxylic acid in human volunteers exposed to 420 mg/m³ (100 ppm) styrene for 8 hours (Cerny *et al*., 1990). Lowered levels of these metabolites have been associated with a reduced risk of CNS disturbances in volunteer workers (Cherry and Gautrin, 1990). Co-exposure to inhaled acetone was reported to alter cytochrome-P450 enzymes as measured by altered urinary steroid metabolites and glucaric acid in workers who consumed moderate amounts of alcohol

(Dolara *et al*., 1983). However, the clinical significance of the presence of these compounds in the urine is unknown.

Styrene is bioactivated to styrene 7,8-oxide, a reactive metabolite which binds to tissue proteins, acts as a hapten, and elicits contact allergy in some individuals (Sjoborg *et al*., 1984). Analyses of styrene oxide adducts bound to human serum albumin have been used as biomarkers for exposure to styrene (Rappaport *et al*., 1993). In a study comparing 9 styrene-exposed workers with 24 healthy controls, hematocrit, blood lead levels, and delta-aminolevulinate dehydrase (ALA-D) levels were measured (Fujita *et al*., 1987). The workers were exposed to at least 210 mg/m³ (50 ppm) styrene for 7 days. Styrene oxide was shown to inhibit the formation of ALA-D, an important enzyme in heme biosynthesis, in these workers. Styrene oxide is also known to bind covalently to DNA *in vitro* (Hemminki and Hesso, 1984).

Two subjects with occupational asthma due to prior exposure to styrene were exposed to 15 ppm (63 mg/m³) styrene in a chamber (Moscato *et al*. (1987). Immediate bronchoconstriction was observed in both subjects while a late rash was also observed in one of the subjects.

Predisposing Conditions for Styrene Toxicity

Medical: Asthmatics may be more sensitive to adverse pulmonary effects from styrene exposure (Moscato *et al*., 1987).

Chemical: Ethanol consumption and acetone inhalation may inhibit the metabolism and clearance of styrene (Cerny *et al*., 1990; Dolara *et al*., 1983; Elovaara *et al*., 1990).

V. Acute Toxicity to Laboratory Animals

The irritant and central nervous system (CNS) depressant effects of styrene in humans are consistent with the acute effects observed in experimental animals (Bond, 1989).

Bonnet *et al*. (1979; 1982) determined a 6 hour LC_{50} in rats and mice of 4,618 ppm (95% confidence interval, 4,399-4,894 ppm) and 2,429 ppm (95% confidence interval, 2,353-2,530 ppm), respectively. Shugeav (1969) also determined the LC_{50} in rats and mice. In rats the 4 hour LC_{50} was 2,810 ppm (95% confidence interval, 2,452-3,214 ppm), and in mice the 2 hour LC_{50} was 5,000 ppm (95% confidence interval, 4,238-5,905 ppm). Jeager *et al*. (1974) estimated the 4 hour LC_{50} in rats to be 2,700 ppm. In other acute lethality studies, 2 of 6 rabbits died following 4 hour exposure to 4,000 ppm styrene (Union Carbide Corp., 1957).

Lundberg *et al*. (1986) could not determine an LC_{50} in rats because the concentrations required for lethality in a 4 hour exposure exceeded the vapor saturation point. No animals died as a result of a 4 hour exposure to 7,904 ppm styrene while 4/10 rats died when exposure at this concentration was extended to 8 hours.

Inhalation of 1,300 ppm (6,000 mg/m³) by rats and guinea pigs resulted in immediate irritation and lacrymation (Spencer *et al*., 1942). No deaths occurred from exposure to 10,000 ppm styrene for

1 hour. However, exposure to this concentration for 3 hours resulted in 100% mortality in both species. This concentration of styrene was the highest that the researchers could attain at room temperature without the chemical condensing out of the atmosphere. At 5,000 ppm, a 100% survival rate was observed following exposure of rats and guinea pigs for 2 and 3 hours, respectively. One-hundred percent mortality was observed at this concentration in both species following 8 hour exposure. Immediate deaths were due to CNS depression. However, delayed deaths occurred due to pulmonary edema and hemorrhage which frequently developed as a result of styrene's acute lung irritant action.

In a study by Morgan *et al*. (1993a), B6C3F1 mice (36 mice/sex/dose) were exposed to 125, 250, or 500 ppm of styrene 6 hours/day for 3 days. Seven of 72 mice died or were terminated moribund following one 6-hour exposure to 500 ppm. Necropsy of dead or dying mice revealed livers engorged with blood. Severe congestion and necrosis of the liver was observed under microscopic examination. Exposure to both 250 and 500 ppm styrene was associated with progressive degenerative and necrotic hepatocellular changes after one 6 hour exposure. There were no significant histologic lesions in mice exposed to 125 ppm styrene. While the liver was identified as the major target organ in mice, the authors indicated that styrene's CNS depressant action also likely contributed to the overall toxicity. Another inhalation study by this research group determined that B6C3F1 mice are more sensitive to styrene induced hepatotoxicity than other common mouse strains, and that kidney toxicity was not seen in any strain of mice investigated following styrene exposure (Morgan *et al*., 1993b).

Morgan *et al*. (1995) conducted additional studies to investigate mouse strain and gender differences in susceptibility to hepatotoxicity caused by repeated exposure to styrene at concentrations that do not cause metabolic saturation. Male and female B6C3F1 and Swiss mice (8 weeks old) were exposed to 0, 150, or 200 ppm styrene for 6 hr/day, 5 days/week, for up to 2 weeks. Changes in body and liver weights, serum enzyme levels, liver histopathology, and total liver glutathione (GSH) were evaluated after 2, 3, 5, and 10 exposures (six mice/sex/strain/time point/concentration). Serum alanine aminotransferase (ALT) and sorbitol dehydrogenase (SDH) levels were significantly elevated only in female B6C3F1 mice after 3 exposures to 200 ppm styrene; enzyme levels had returned to control levels when measured after 5 and 10 exposures. Degeneration and coagulative necrosis of centrilobular hepatocytes were observed in female B6C3F1 mice exposed 2, 3, and 5 days to 150 or 200 ppm styrene; incidences of these lesions were greater in the 200 ppm than in the 150 ppm dose group. After 10 days of exposure to 150 or 200 ppm styrene, hepatocellular lesions had resolved, although a residual chronic inflammation was present in livers of most female B6C3F1 mice.

The acute inhalation toxicity adverse effects in mice do not appear to be consistent with adverse effects seen in humans and other animal species. In research by Mendrala *et al*. (1993) and a review by Sumner and Fennell (1994), comparison of the metabolic fate of styrene and its toxic metabolite, styrene oxide, in mice, rats, and humans showed that mice are more sensitive than rats and humans to the hepatotoxic effects of styrene. Based on P450 enzyme kinetics (the primary enzymes responsible for metabolizing styrene to styrene oxide) and the relative liver and body size, the mouse had the greatest capacity to form styrene oxide from styrene. In mice exposed to relatively low levels of styrene (250 to 500 ppm), the blood concentration of the metabolite

styrene oxide rises steeply, potentially resulting in hepatotoxicity and mortality. This metabolic phenomenon does not occur in rats or humans. In addition, hepatotoxicity has not been reported for rats, and there have not been epidemiological findings of hepatotoxicity in humans exposed to styrene.

Sumner at al. (1997) compared the metabolism and hepatotoxicity (mice only) of styrene in male B6C3F1 mice, CD-1 mice, and F344 rats to evaluate mechanisms of toxicity. Rats and mice were exposed to 250 ppm styrene for 6 h/day for 1 to 5 days. Mortality and increased serum ALT activity were observed in mice but not in rats. Hepatotoxicity in B6C3F1 mice was characterized by severe centrilobular congestion after one exposure followed by acute centrilobular necrosis. Hepatotoxicity was delayed by 1 day in CD-1 mice, and the increase in ALT and degree of necrosis were less than in B6C3F1 mice. After exposure to (unlabeled) styrene for 0, 2, or 4 days, rats and mice were exposed to [7-^{14}C]-styrene (60 μCi/mmol) for 6 h. Most styrene-derived radioactivity was excreted in urine; the time-course indicated that rats and CD-1 mice eliminated radioactivity at a faster rate than B6C3F1 mice following a single 250 ppm exposure, consistent with a greater extent of liver injury for B6C3F1 mice. The elimination rate following 3 or 5 days of exposure was similar for rats and the two mouse strains. After three exposures, the total radioactivity eliminated was elevated over that measured for one exposure for both mouse strains. An increased excretion of metabolites on multiple exposure is consistent with the absence of ongoing acute necrosis following 4 to 5 daily exposures. The data indicate that an induction in styrene metabolism occurs after multiple exposures.

Pretreatment of rats with acetone potentiated pulmonary toxicity, measured by decreased lung glutathione and cytochrome-P450 activity following inhalation of 2,100 mg/m^3 styrene vapor 5 hours/day for 3 days (Elovaara *et al*., 1990).

Styrene has been shown to suppress antibody responses and to enhance hypersensitivity responses in mice after multiple administrations of 20 mg/kg for 5 days (Dogra *et al*., 1989).

VI. Reproductive or Developmental Toxicity

There is no direct evidence for human reproductive or developmental toxicity from styrene exposure.

Murray *et al*. (1978) found no teratogenesis or reproductive impairment in rats or rabbits inhaling styrene concentrations up to 600 ppm (2,520 mg/m^3) throughout critical days of gestation. Decreased maternal body weight gain was observed in rats but not rabbits. Other studies in rodents have supported this finding (Daston *et al*., 1991; Srivastava *et al*., 1989). A comprehensive review on the subject could find no evidence for reproductive and developmental toxicity in experimental animals or humans (Brown, 1991). Likewise, a review of epidemiological studies could find no evidence of reproductive health effects in women due to occupational exposure to styrene (Lindbohm, 1993).

Kishi *et al*. (1995) exposed pregnant Wistar rats via inhalation to 0, 50, or 300 ppm styrene for 6 h/day during gestation days 7 to 21. Offspring were evaluated in several neurobehavioral tests.

Initial results with a few litters showed significant dose-dependent effects in tests performed pre-weaning (surface righting, pivoting locomotion, and bar holding) and in tests performed post-weaning (motor coordination, open-field behavior, and motor activity). Exposure to 50 ppm styrene caused disturbances in motor coordination and delayed some motor and reflex developments, and 300 ppm led to changes in open-field behavior, increases in spontaneous activity, and delay in neurobehavioral developments. Exposure of dams to styrene did not clearly affect the learning behavior of the offspring. Age played a role in the differences in styrene's effects on neurobehavioral function. At 120 days after birth only subtle effects were found in both open-field behavior and motor-coordination function when compared with control rats.

Exposure of rats and rabbits to the reactive metabolite, styrene oxide, at 100 ppm throughout gestation resulted in reproductive and developmental toxicity, as well as maternal toxicity (Sikov *et al*., 1986).

VII. Derivation of Acute Reference Exposure Level and Other Severity Levels (for a 1-hour exposure)

Reference Exposure Level (protective against mild adverse effects): 5.1 ppm (21,000 μg/m³)

Study	Stewart *et al*., 1968
Study population	three human volunteers
Exposure method	inhalation
Critical effects	eye and throat irritation
LOAEL	99 ppm (for 20 minutes)
NOAEL	51 ppm
Exposure duration	1 hour
Extrapolated 1 hour concentration	51 ppm
LOAEL uncertainty factor	1
Interspecies uncertainty factor	1
Intraspecies uncertainty factor	10
Cumulative uncertainty factor	10
Reference Exposure Level	5.1 ppm (21 mg/m³; 21,000 μg/m³)

Level Protective Against Severe Adverse Effects

Human subjects exposed to 376 ppm styrene for 25 minutes developed significant decrements in coordination and manual dexterity as well as nausea and discomfort (Stewart *et al*., 1968). These effects were not observed in subjects exposed to 216 ppm for 1 hour. An uncertainty factor of 10 was applied to the 1-hour NOAEL of 216 ppm to account for increased susceptibility of sensitive human individuals. The resulting level protective against severe adverse effect is 22 ppm (91 mg/m³) for a 1-hour exposure to styrene. However, sensitized individuals may be unable to tolerate exposure to styrene at detectable levels (Moscato *et al*., 1987; Hayes *et al*., 1991). Therefore, these individuals may not be protected by the severe adverse effect level developed for styrene in this document.

Level Protective Against Life-threatening Effects

Spencer *et al*. (1942) observed a NOAEL for lethality in rats and guinea pigs of approximately 10,000 ppm for a 1-hour exposure. This was consistent with the lack of mortality observed following exposure for 2- to 3-hours at 5,000 ppm. The LOAEL for lethality was 10,000 ppm for a 3-hour exposure. Although more recent lethality studies in rats exist (Lundberg *et al*. 1986), the Spencer *et al*. (1942) report was the only study that was known to include a post-exposure observation period (2-4 weeks) long enough to observe delayed mortality due to pulmonary injury. The lethal hepatic effect observed in mice following exposure to styrene is inconsistent with that seen in humans for acute exposures via inhalation. Therefore, a life-threatening level based on mouse exposure data does not appear to be appropriate. Uncertainty factors of 10 each were applied to the NOAEL (10,000 ppm) to account for interspecies differences and increased susceptibility of sensitive human individuals. The total uncertainty factor incorporated was 100, resulting in a level of 100 ppm (420 mg/m^3) protective against life-threatening effects for a 1-hour exposure to styrene.

NIOSH (1995) reports an IDLH of 700 ppm based on acute inhalation toxicity in human workers. There is no allowance made for sensitive individuals.

VIII. References

(ATSDR) Agency for Toxic Substances and Disease Registry. Toxicological profile for styrene. Atlanta: ATSDR; 1992.

Amoore JE, Hautala E. Odor as an aid to chemical safety: Odor thresholds compared with threshold limit values and volatilities for 214 industrial chemicals in air and water dilution. J Appl Toxicol 1983;3(6):272-290.

Bond JA. Review of the toxicology of styrene. CRC Crit Rev Toxicol 1989;19(3):227-249.

Bonnet P, Raoult G, Gradiski D. Concentrations lethales 50 des principaux hydrocarbures aromatiques. [LC_{50}s of common aromatic hydrocarbons.] Arch Mal Med Trav Secur Soc 1979;40:805-10.

Bonnet P, Morele Y,Raoult G, Zissu D, Gradiski D. Determination de la concentration lethale$_{50}$ des principaux hydrocarbures aromatiques chez le rat. [Determination of the LC_{50} of common aromatic hydrocarbons in th rat.] Arch Mal Med Trav Secur Soc 1982;43:261-5.

Brown NA. Reproductive and developmental toxicity of styrene. Reprod Toxicol 1991;5:3-29.

Carpenter CP, Shaffer CB, Weil CS, Smyth HF Jr. Studies on the inhalation of 1,3 butadiene; with a comparison of its narcotic effect with benzol, toluol, and styrene, and a note on the elimination of styrene by the human. J Ind Hyg Toxicol 1944;26:69-77.

Cerny S, Mraz J, Flek J, Tichy M. Effect of ethanol on the urinary excretion of mandelic and phenylglyoxylic acids after human exposure to styrene. Int Arch Occup Environ Health 1990;62:243-247.

Cherry N, Gautrin D. Neurotoxic effects of styrene: further evidence. Br J Ind Med 1990;47:29-37.

Daston GP, Overmann GJ, Taubeneck MW, Lehman-McKeeman LD, Rogers, JM, Keen CL. The role of metallothionein induction and altered zinc status in maternally mediated developmental toxicity: comparison of the effects of urethane and styrene in rats. Toxicol Appl Pharmacol 1991;110:450-463.

Dogra RKS, Khanna S, Srivastava SN, Shukla LJ, Shanker R. Styrene-induced immunomodulation in mice. Int J Immunopharmacol 1989;11(5):577-586.

Dolara P, Lodovici M, Salvadori M, Santoni G, Caderni G. Enzyme induction in humans exposed to styrene. Ann Occup Hyg 1983;27(2):183-188.

Edling C, Ekberg K. No acute behavioral effects of exposure to styrene: a safe level of exposure? Br J Ind Med 1985;42:301-304.

Elovaara E, Vainio H, Aitio A. Pulmonary toxicity of inhaled styrene in acetone-, phenobarbital- and 3-methylcholanthrene-treated rats. Arch Toxicol 1990;64:365-369.

Fujita H, Koizumi A, Furusawa T, Ikeda M. Decreased erythrocyte δ-aminolevulinate dehydratase activity after styrene exposure. Biochem Pharmacol 1987;36(5):711-716.

Gamberale F, Hultengren M. Exposure to styrene II. Psychological functions. Work Environ Health 1974;11:86-93.

Götell, P., Axelson, O., Lindelöf, B. 1972. Field studies on human styrene exposure. Work Environ Health 1972;9:76-83.

Harkonen H, Lindstrom K, Seppalainen AM, Sisko A Hernberg S. Exposure-response relationship between styrene exposure and central nervous functions. Scand J Work Environ Health 1978;4:53-59.

Hayes JP, Lambourn L, Hopkirk JAC, Durham SR, Newman Taylor AJ. Occupational asthma due to styrene. Thorax 1991;46:396-397.

Hemminki K, Hesso A. Reaction products of styrene oxide with guanosine in aqueous media. Carcinogenesis 1984;5(5):601-607.

(IARC) International Agency for Research on Cancer. Monographs on the evaluation of the carcinogenic risk of chemicals to man. Some monomers, plastics and synthetic elastomers, and acrolein. Vol. 19. Geneva: World Health Organization; 1979. p. 231-274

Jaeger RJ, Conolly RB, Murphy SD. Toxicity and biochemical changes in rats after inhalation exposure to 1,1-dichloroethylene, bromobenzene, styrene, acrylonitrile or 2-chlorobutadiene. Toxicol Appl Pharmacol 1974;29:81.

Kishi R, Chen BQ, Katakura Y, Ikeda T, Miyake H. Effect of prenatal exposure to styrene on the neurobehavioral development, activity, motor coordination, and learning behavior of rats. Neurotoxicol Teratol 1995;17(2):121-130.

Leibman KC, Ortiz E. Epoxide intermediates in microsomal oxidation of olefins to glycols. J Pharmacol Exp Ther 1970;173:242-246.

Lindbohm M-L. Effects of styrene on the reproductive health of women: a review. In: Sorsa M, Peltonen K, Vainio H, Hemminki K, editors. Butadiene and styrene: assessment of health hazards. IARC Scientific Publications No. 127. Lyon, France: International Agency for Research on Cancer; 1993. p. 163-169.

Lorimer WV, Lilis R, Nicholson WJ, Anderson H, Fischbein A, Daum S, *et al*. Clinical studies of styrene workers: initial findings. Environ Health Perspect 1976;17:171-181.

Lundberg I, Ekdahl M, Kronevi T, Lidums V, Lundberg S. Relative hepatotoxicity of some industrial solvents after intraperitoneal injection or inhalation exposure in rats. Environ Res 1986;40:411-420.

Mendrala AL, Langvardt PW, Nitschke KD, Quast JF, Nolan RJ. In vitro kinetics of styrene and styrene oxide metabolism in rat, mouse, and human. Arch Toxicol 1993;67:18-27.

Morgan DL, Mahler JF, Dill JA, Price HC Jr, O'Conner RW, Adkins B Jr. Styrene inhalation toxicity studies in mice. II. Sex differences in susceptibility of B6C3F1 mice. Fundam Appl Toxicol 1993a;21:317-325.

Morgan DL, Mahler JF, Dill JA, Price HC Jr, O'Conner RW, Adkins B Jr. Styrene inhalation toxicity studies in mice. III. Strain differences in susceptibility. Fundam Appl Toxicol 1993b;21:326-333.

Morgan DL, Mahler JF, Moorman MP, Wilson RE, Price HC Jr, Richards JH, O'Connor RW. Comparison of styrene hepatotoxicity in B6C3F1 and Swiss mice. Fundam Appl Toxicol 1995 27(2):217-222.

Moscato G, Biscaldi G, Cottica D, Pugliese F, Candura S, Candura F. Occupational asthma due to styrene: Two case reports. J Occup Med 1987;29(12):957-960.

Murray FJ, John JA, Balmer MF, Schwetz BA. Teratologic evaluation of styrene given to rats and rabbits by inhalation or by gavage. Toxicology 1978;11:335-343.

Rappaport SM, Ting D, Jin Z, Yeowell-O'Connell K, Waidyanatha S, McDonald T. Application of Raney Nickel to measure adducts of styrene oxide with hemoglobin and albumin. Chem Res Toxicol 1993;6:238-244.

Sedivec V, Flek J, Mraz M. Urinary excretion of mandelic and phenylglyoxylic acids after human exposure to styrene vapor. J Hyg Epidemiol Microb Immunol 1984;28(3):241-255.

Shugaev BB. Concentrations of hydrocarbons in tissues as a measure of toxicity. Arch Environ Health 1969;18:878-882.

Sikov MR, Cannon WC, Carr DB, Miller RA. Niemeier RW, Hardin B D. Reproductive toxicology of inhaled styrene oxide in rats and rabbits. J Appl Toxicol 1986;6(3):155-164.

Sjoborg S, Fregert S, Trulsson L. Contact allergy to styrene and related chemicals. Contact Dermatitis 1984;10:94-96.

Spencer HC, Irish DD, Adams EM, Rowe VK. The response of laboratory animals to monomeric styrene. J Ind Hyg Toxicol 1942;24(10):295-301.

Srivastava S, Seth PK, Srivastava SP. Effect of styrene administration on rat testis. Arch Toxicol 1989;63:43-46.

Stewart RD, Dodd HC, Baretta ED, Schaffer AW. Human exposure to styrene vapor. Arch Environ Health 1968;16:656-662.

Sumner SJ, Fennell TR. Review of the metabolic fate of styrene. CRC Crit Rev Toxicol 1994;24(S1):S11-S33.

Sumner SC, Cattley RC, Asgharian B, Janszen DB, Fennell TR. Evaluation of the metabolism and hepatotoxicity of styrene in F344 rats, B6C3F1 mice, and CD-1 mice following single and repeated inhalation exposures. Chem Biol Interact 1997;106(1):47-65

Union Carbide Corporation. 1957. [cited in: IARC, 1979.]

Vainio H, Hietanen E. Styrene. In: Snyder R, editor. Ethel Browning's toxicity and metabolism of industrial solvents. 2nd ed. Vol. I. Hydrocarbons. New York: Elsevier; 1987. p. 199-208.

Wolf MA, Rowe VK, McCollister DD, Hollingsworth RL, Oyen F. Toxicological studies of certain alkylated benzenes and benzene. AMA Arch Ind Health 1956;14:387-398.